DYNAMICS OF SEMI-ENCLOSED AND COASTAL SEAS: NUMERICAL MODELS AND ALTIMETRY

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Long Term Goals

Our long term research goal is to obtain a better understanding of the circulation and other processes in semi-enclosed, marginal and coastal seas of naval interest. Another goal is to assist the establishment of a nowcast/forecast capability. The primary tools of investigation for this purpose are remote sensing, principally altimetry, and comprehensive, data-assimilative numerical models assimilating altimetric and other remotely-sensed data.

Objectives

The near term objective is to examine the utility of altimetric data, both in shallow waters of the coastal seas, and in marginal seas. The regions of current focus are the Yellow/East China Sea and the Sea of Japan. Our immediate objective is to examine the utility of altimetric data assimilation in numerical models of these seas for nowcast/forecast applications and process studies.

Approach

The approach is to extract sub-tidal signals from altimetric data from current (NASA/CNES TOPEX/Poseidon, ESA ERS-2) missions, using standard analysis techniques but subtracting tidal signals accurately using our regional/global tidal models, and to assimilate them in comprehensive 3-D circulation models of marginal seas. The uniqueness is in combining data from multiple altimeters with numerical models to better simulate the physical state. This helps us better understand physical processes and produce more accurate nowcasts.

Work Completed

We have used altimetric data to study the SSH variability in many semi-enclosed seas of naval interest. A high resolution (1/5 degree), fully nonlinear global barotropic model, assimilating altimetric tides in the deep ocean and tide gage data along the world's coasts has also been completed (Kantha 1995).

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We have analyzed the TOPEX 1 Hz data for internal tides in the global oceans (Kantha and Tierney 1996, 1997). We are also examining the TOPEX 10 Hz data to discern small scale processes in the global oceans, specifically for evidence of internal wave solitons in altimetric data.

Finally, we have ingested altimetric and MCSST data into a three dimensional model of the Sea of Japan. We have also assisted NRL/Stennis in developing and transitioning a 3-D Yellow Sea circulation model with complete tidal forcing. We have also continued to assist NAVO/Stennis in their development and testing of operational models of various semi-enclosed seas and in running our relocatable tidal model in various regions of their interest.

Results

As a result of this study, we have one of the only two global tidal models that are currently useful in both deep and shallow waters around the world (Kantha 1995, Kantha et al. 1995, see also http://www.cast.msstate.edu/Tides2D). This model has several uses: 1. For altimetric analyses in any coastal and marginal sea around the world, 2. For providing boundary conditions to very high resolution nested regional tidal models, both barotropic and baroclinic, and 3. For geophysical applications (Kantha et al. 1995). The model is one of the ten distributed by NASA Jet Propulsion Laboratory on a CD-ROM as a TOPEX/Poseidon (T/P) mission product. Our tidal model results and altimetry in marginal seas (altimetric results for most marginal and semi-enclosed seas can also be found on the Web at http://www.cast.msstate.edu/ Altimetry) have been used by many people around the world.

Out of about 3.5 TW of tidal power input to the global ocean by the Moon and the Sun (2.4 TW in M2 alone), it is thought that fully 20% is by conversion to baroclinic (internal) tides along mid-ocean ridges and seamounts. It is also thought that internal tides (IT) are a major source of the deep sea internal wave field and mixing, and perhaps thermocline maintenance (Munk and Wunsch 1998). However, there have been only very sparse IT measurements in the global oceans. We have managed to identify their small SSH signatures in the highly accurate data from the high precision TOPEX altimeter, and thereby provide a global view of IT for the first time. We estimate the baroclinic dissipation to be about 600 GW, the very first time this number has been deduced reliably from observations. The results were presented at the Royal Society meeting (Kantha and Tierney 1996) and a paper has been accepted for publication in the Cartwright anniversary volume of Progress in Oceanography (Kantha and Tierney 1997). A 3-D model of internal tides is being tested in the Indian Ocean, which has one of the largest observed internal tides around the Mascaren Ridge, by Scott Stewart, one of our doctoral students. The results will help firm up the fraction of tidal dissipation in baroclinic tides.

For nearly 200 years, long period tides (LPT) have defied a complete understanding (Wunsch 1967, Miller et al. 1993) and their basic nature (whether tide-like or general circulation-like) has been debated. LPT are the major tidal signal in the length of day (LOD) fluctuations. Using TOPEX data assimilated into a global model, we have derived a reliable picture of the Mf and Mm tides in the global oceans, that sheds some light on the controversy, and also help remove LPT signals from geophysical measurements (and

altimetric signals) and gain insight into the workings of the Earth's core and mantle. The results are consistentwith those of Carl Wunsch's group that used a highly idealized non-assimilative model of LPT. A paper has been submitted to the Journal of Geophysical Research. A review paper on the topic of tides (Kantha 1998) has been submitted to the Geophysical Journal.

A seven year climatological simulation of the Sea of Japan (East Sea) shows features consistent with the current understanding of the circulation there (Suk et al. 1996). The seasonal fluctuations of the East Korea Warm Current, and the Japan Coastal Current, the two branches of the Tsushima/Korea Current flowing into the Sea are well depicted. So are the Uleung and Yamato Eddies. The general features of the surface circulation agree well with those inferred from MCSST and in-situ observations. For a long time, the currents in the Sea well below the sill levels were thought to be weak and sluggish, but recent current meter observations from CREAMS show currents as strong as 30 cm/s. The model appears to as well.

Finally, altimetric data have been assimilated into the Sea of Japan model during 1993 to assess the feasibility of reproducing some of the meso-scale features observed along the 40 N thermal front by altimetry and drifting buoys (Bang et al. 1996). In spite of the small signatures of these features and difficulty of sampling them by a single altimeter, it has been possible to reproduce them in the data-assimilative model. The model has been updated to assimilate both MCSST and altimetry and tested in a hindcast mode for 1993 (Suk and Kantha 1998). Figure 1 shows the surface currents from this run. A real-time nowcast/forecast capability for this Sea appears feasible.

Many of these results have been presented at the 1995 IUGG meeting at Boulder, the 1995 IAPSO meeting in Hawaii, and the Fall 1996 AGU meeting in San Francisco. Major new findings are being reported at the 1998 Ocean Sciences meeting in San Diego in February 1998.

Impact/Applications

We have demonstrated the utility of altimetry to naval applications in marginal seas. With the CU global tidal model that is uniformly valid everywhere, including the shallow coastal seas (not just in the deep primary basins), we have the capability, in principle, to do tides and altimetry anywhere in the global oceans, and along any coast in the world. This has important implications to naval operations and the Navy's GEOSAT Follow On altimetric mission. Sciencewise, the small scale processes discernible in altimetry may be useful to understanding the small scale variability in the global oceans, including the shallow shelf regions so long ignored in altimetry. For the first time, we have been able to quantify tidal energetics (see Table 1), and estimate reliably the tidal dissipation in baroclinic tides, a matter of great importance to deep-sea mixing and thermocline maintenance (Munk and Wunsch 1998). Real-time nowcast/forecast capability capability in marginal seas is a real asset to the Navy.

Transitions

Helped transition to NAVO the CU rapidly relocatable regional tidal model. The latter is being applied by NAVO personnel to some high priority regions in the western Pacific.

Related Projects

We work very closely with MSU CAST (on relocatable regional models), and NAVO (Horton et al. 1997, Clifford et al. 1997) in this and related projects. There is a close scientific collaboration and exchange with the Korean and Japanese scientists studying their marginal seas (We are part of the upcoming JES DRI). Our accomplishments would not have been possible however without leveraging the substantial NASA and other funding to our group for altimetric and modeling research respectively. For example, under oil industry consortium funding, we have setup a real-time nowcast/forecast system for the Gulf of Mexico (http://www-ccar.colorado.edu/~jkchoi/gomforecast.html).

References*

Miller, A. J., D. S. Luther and M. Hendershott, The fortnightly and monthly tides: resonant Rossby waves or nearly equilibrium gravity waves?, J. Phys. Oceanogr., 23, 879-897, 1993.

Munk, W., Once again - Once again - Tidal dissipation, Prog. Oceanogr., David Cartwright anniversary volume (in press) (Also presented at the Royal Society of London Meeting on Tides, London, October 21-22, 1996).

Munk, W., and C. Wunsch, The Moon and mixing: Abyssal Recipes II, Unpublished manuscript, 1998.

Wunsch, C., The long-period tides, Rev. Geophys. Space Phys., 5, 447-475, 1967.

* See our publications list for references missing from this list.

Table 1: Tidal Energetics[o]

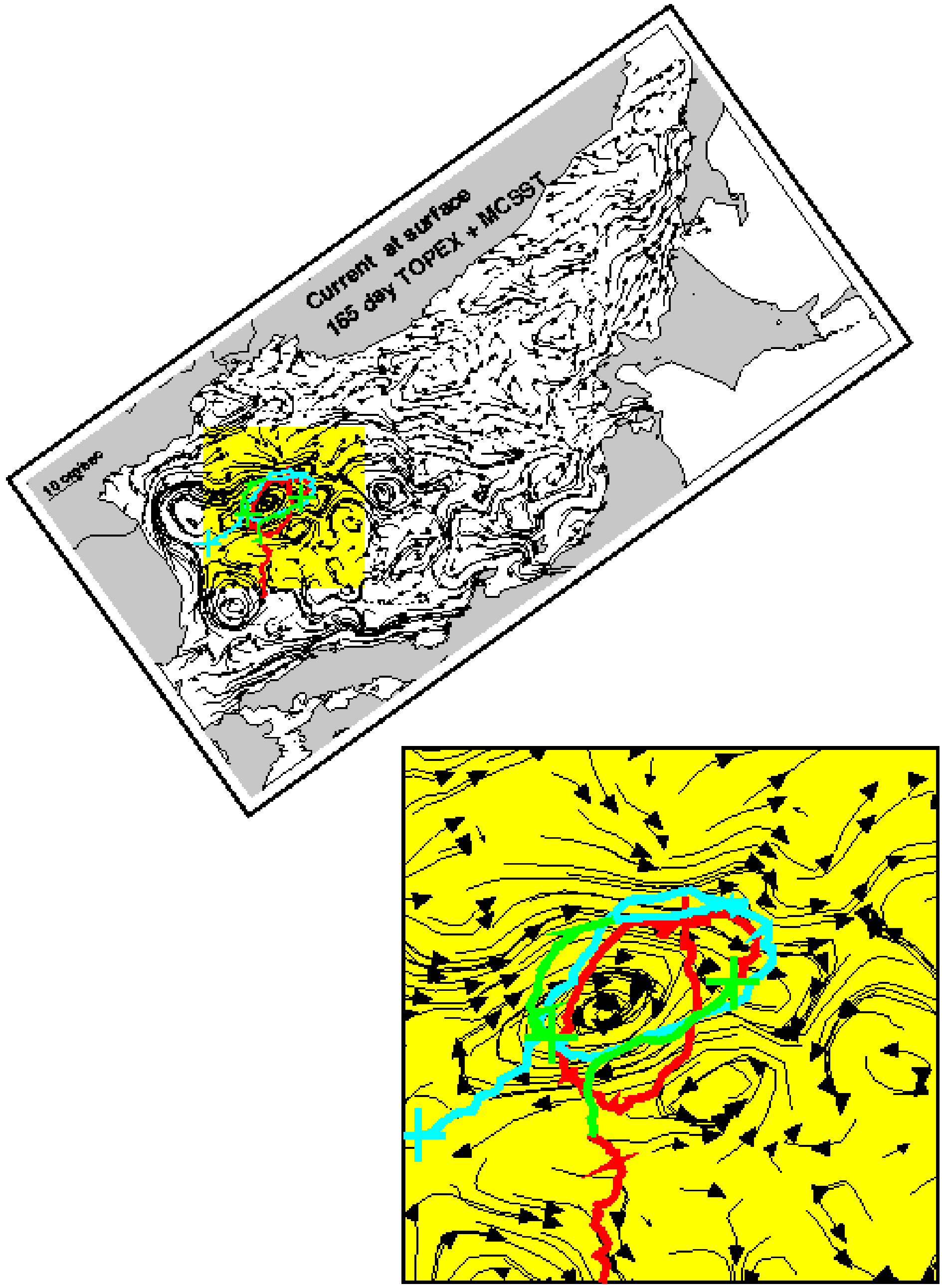
Barotropic Tides:

Comp	**Power[*]** (GW)	KE (PJ $=10^{15}$ J)	**TE**	PE/KE	Q	Period (hr/dy)	Power (Relative to M_2)	TE	Eq PE[#] (PJ)	TE Den[+] (J m^{-2})
M_2	**2572.6**	242.0	**392.0**	0.62	**23.03**	12.42	1.0	1.0	30.49	**1153**
S_2	410.3	38.0	65.0	0.71	24.81	12.00	0.159	0.165	6.60	191
N_2	117.8	11.6	18.8	0.62	23.78	12.66	0.046	0.048	1.12	55
K_2	30.1	3.1	5.4	0.74	28.12	11.97	0.012	0.014	0.49	16
K_1	378.7	36.0	55.5	0.54	11.57	23.93	0.147	0.220	9.71	163
O_1	193.5	27.0	37.4	0.39	14.12	25.82	0.075	0.146	4.91	110
P_1	40.6	5.6	7.7	0.38	14.69	24.07	0.016	0.024	1.06	23
Q_1	8.2	1.1	1.5	0.43	12.82	26.87	0.003	0.008	0.18	4
Mf	0.369	0.240	0.381	0.59	5.90	(13.66)	$O(10^{-4})$	$O(10^{-3})$	0.245	1.13
Mm	0.022	0.013	0.049	2.91	6.20	(27.55)	$O(10^{-6})$	$0(10^{-4})$	0.068	0.14
All 4 SD	3130.8	294.7	481.2	0.633	23.22 (Based on M_2 freq)		1.217	1.227	38.70	1415
All 4 D	621.0	69.7	102.1	0.46	12.89 (Based on K_1 freq)		0.241	0.397	15.86	300
Lunar	**3170.4**	308.7	**491.7**	0.593	M_2,N_2,O_1,Q_1,Mf,Mm + 0.68(K_2,K_1)		1.232	1.372	43.95	**1446**
Solar	581.7	56.1	92.2	0.643	S_2,P_1 + 0.32(K_2,K_1)		0.226	0.264	10.92	271
All	**3752.1**	364.8	**583.9**	0.600			1.458	1.637	1.861	**1717**

Baroclinic tides:

Comp	**Diss.** (GW)	**TE** (PJ)	TE Den[x] J m^{-2}	Q	**Alt.TE** (PJ)	Alt.TE Den[x] J m^{-2}
M_2	**360**	**50**	**167**	19.5	**50**	**167**
S_2	57	8	27	20.4	?	?
K_1	42	15	50	26.0	?	?
All4 S	440	61	203	19.5	?	?
All4 D	81	29	97	26.1	?	?
All	**521**	**90**	**300**		?	?

o Excluding the Arctic Ocean
* Includes solid Earth and load tides; Divide by 1.075 to get values for ocean tides only
\# Energy expected if tides were in equilibrium
\+ Based on global ocean area of 3.4 x 10^{14} m^2 (excluding the Arctic)
x Based on ocean area of 3 x 10^{14} m^2 (equatorward of 60^o latitude)



Surface Currents from the Model (T2) with TOPEX & MCSST Assimilation. Note the Strong Anti-cyclonic Eddy.